Instrumented Tools and Modular Components for Robotic Assembly

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***Abstract*— We describe a robotic assembly system which uses optical communication between a robotic manipulator and a set of active assembly materials to perform reliable part identification and grasping. The hardware design of a manipulator and a set of modular assembly materials capable of optical communication is introduced. A communication protocol and an algorithm for reliable grasping are given. We present experimental results in which modular assembly materials are selected, localized, and grasped with high reliability using a low-cost manipulator.**

I. Introduction

Conventional approaches to automated assembly have centered on specialized robots in dedicated work envelopes with stages of assembly linked by conveyor belt. Consequently, automated assembly is currently synonymous with high factory design and deployment time. However, the product design cycle continues to tighten under pressures to get new products to market faster. The need for faster, more flexible deployment of production could be met by replacing rigidly defined conventional robots with assembly robots capable of finding and manipulating assembly materials within a loosely structured environment.

Could discuss related works here, or talk about the possibilities created by groups of cooperative assembly robots and the intelligent components...

A. Solution overview

A flexible robotic assembly system requires robots to correctly identify materials and accurately manipulate them. Using assembly materials and a gripper end-effector endowed with two-way infrared (IR) optical communication, part identification and position sensing can be performed using local messaging. Part identification is accomplished immediately by simply requesting that an assembly material transmit information about itself. This provides a simple alternative to vision-based identification techniques. Additionally, the optical communication, as a line-of-sight medium, is used as a sensing modality to sense the position of assembly materials. The field-of-view and range of the gripper's optical transceiver constrain the position of any assembly material in communication contact to be inside a cone originating from the gripper. This information is used during grasping to guide the gripper to the assembly component's position.

This work was supported in part by the Boeing Corporation

II. Intelligent Assembly Hardware

In this work, we develop a robotic assembly system that uses optical communication to reliably identify and grasp modular assembly materials. This system utilizes a mobile robot platform equipped with a laptop PC and a 5-DOF manipulator, a gripper capable of IR communication, and a set of active assembly materials also capable of IR communication.

A. Mobile robot assembly platform

Our work uses a mobile assembly robot platform comprised of an iRobot Create mobile robot equipped with a laptop PC and a (Brand?) 5-DOF manipulator arm. One such robot is depicted in Fig. 1. The manipulator is equipped with an Intelligent Gripper end-effector, defined below. This robotic platform was designed to utilize low-cost, commercially available components.

Fig. 1. Mobile assembly robot

B. Intelligent gripper

The intelligent gripper mounted on the robot's manipulator arm solves several problems faced by assembly robots. First, its contoured design allows it to reliably grasp assembly materials despite centimeter-scale uncertainty in the material's position. It does this by passively aligning the grasp point into a unique orientation as the gripper closes.Second, the gripper allows the robot to identify individual materials. It accomplishes this by using an IR receiver/transmitter PCB to wirelessly communicate with nearby Intelligent Assembly

Components. The gripper uses an Atmega8 AVR mircocontroller that interfaces with the robot's PC via serial port to perform IR communication. In effect, the gripper can "ask" the things in front of it if they are "graspable". Third, the instrumented gripper provides information about the position of nearby assembly materials by exploiting the FOV of its IR communication. Establishing communication with a part implies that the part is in a circular region below the gripper. The FOV of the gripper is determined by an adjustable aperature in the gripper's transmitter housing.

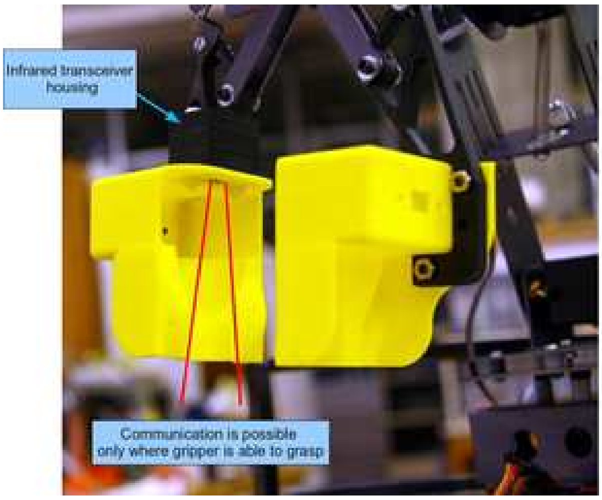

Fig. 2. Intelligent Gripper with infrared transceiver

C. Intellligent assembly materials

A collection of modular junction and strut assembly materials are designed to facilitate sensing, grasping, and construction. Each component contains a communication PCB with an Atmega8 AVR microcontroller and four bidirectional IR transmitter/receiver channels. The AVR contains the unique identification number of the part as well as data about the part, such as its physical type and color. The communication PCB also provides nearly omnidirectional wireless communication via its four IR transmitters and receivers. These allow an assembly material to communicate with robots or other materials reliably at distances of up to 60cm. Using a 3.7v 210mA rechargeable Lithium-Polymer and switching DC-DC converter, the node PCB can be run at 5v for between 4 and 15 hours continuously, depending on the ratio of time idle and time transmitting. The physical shape of the junctions and struts allow passive alignment with eachother and with the assembly robot's gripper.

III. Communication Infrastructure

Communication between the robot's gripper and the assembly materials is made possible by a two-layer communication infrastructure. The first layer is responsible for transmitting packets of information over modulated IR. The second layer defines the message protocol which is used to read and write information stored in the assembly components.

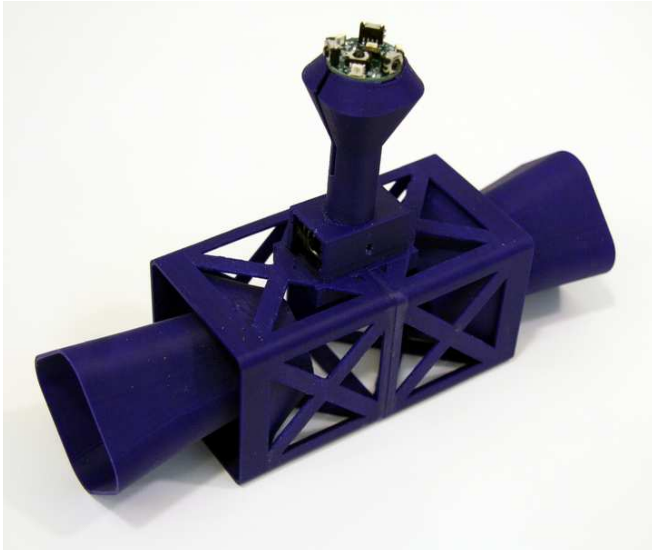

Fig. 3. A modular assembly strut

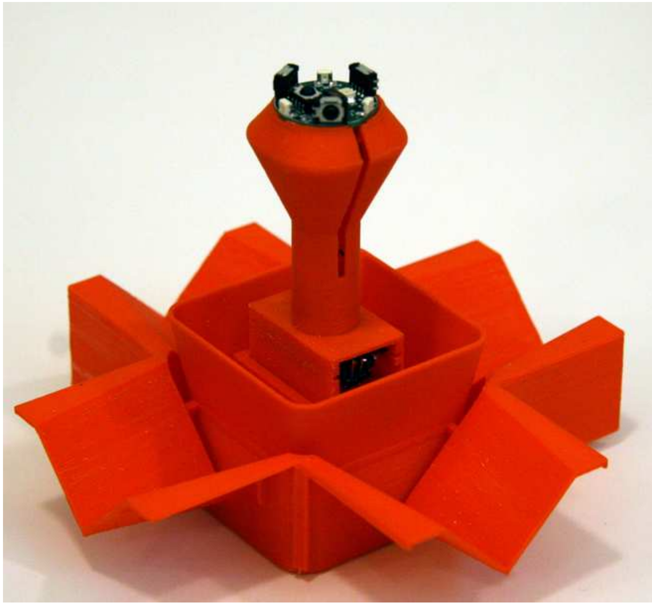

Fig. 4. A modular assembly junction

A. Infrared Packet Layer

The first layer of the communication infrastructure constructs, transmits, and receives packets of information using modulated IR. A packet is defined by unique start and end characters, and contains a CRC16 checksum for error detection. Packet data is transmitted serially using an IR LED modulated at 38kHz. A serial data rate of 2400 bits per second is used. A demodulating receiver allows reliable communication of ranges of up to 3 meters. The packet layer performs half-duplex communication.

B. Messaging Protocol

The second layer of the communication infrastructure is the messaging protocol. These messages define the interactions between the robot and the intelligent assembly materials. All messages make use of the unique identification number assigned to each assembly material and the assembly robot to specify the sender and recipient of each message. The protocol also reserves a $Broadcast\_ID$; a message sent to this address will be responded to by every device which receives it.

The intelligent gripper makes one attempt to retransmit a message if it receives a corrupted response. However, if a construction material receives a corrupted message, it makes no response.

The messaging protocol specifies a collection of messages and how the elements of our system must respond to each message. The messages are enumerated below.

1) Query Message: The $Query$ message is the way that the intelligent gripper accesses information stored within an individual assembly material. The $Query$ message requests that this information be transmitted.

2) Set Message: The Set Message allows the intelligent gripper to set the contents of an assembly material's internal memory.

3) ID Message: The ID essage is transmitted in response to a $Query$ message. The $IDMessage$ indicates the address ID of the transmitting part, and contains the string of data contained in the part volatile memory.

4) Acknowledge Message: The $AckMessage$ is transmitted by an assembly material in response to an error-free $SetMessage$.

5) ForwardMessage: The $ForwardingMessage$ allows the range of communication to be extended beyond simple line-of-sight transmissions. The $ForwardingMessage$ uses a time-to-live number to implement a limited flood routing system. In this system, a $ForwardingMessage$ is created with a time-to-live number. When received, the recipient processes the forwarded message, then decrements the time-to-live number. If the decremented time-to-live number is greater than zero, a new $ForwardingMessage$ is transmitted using this number. This allows messages to propagate through a network of assembly materials while avoiding indefinite propagation.

The protocol requires that an assembly material delay for a random interval of time before forwarding. This helps avoid network congestion. Currently, delays between 0 and 2 seconds are used.

IV. LOCATE-AND-GRASP ALGORITHM

This section defines the $Locate-and-Grasp$ algorithm. This algorithm assumes that assembly materials, if present, are located within a narrow recangular region called the "depot", but that the exact position and type of materials in the depot is not known. The algorithm performs a 1-D searche for an assembly material with a specific ID number or type, and terminates when the robot grasps the part or determines that no such part is present in the depot. The algorithm makes use of the $Query$ and ID messages defined in Sec. III-B.

The $Locate - and - Grasp$ algorithm begins with depot within reach of the assembly robot. The robot's gripper is oriented above one end of the linear depot. The algorithm first locates a desired part to an approximate position estimate. Then, a fine-sensing pass is performed to accurately position the gripper over the component. The grasping algorithm is outlined in Algorithm 1.

Once the robot has positioned its gripper over one end of the linear depot, the first phase begins. The robot begins moving its gripper over the depot, issuing $Query$ messages at regular intervals during the linear motion. These intervals are specified to be shorter than the width of the gripper's FOV so that successive communications overlap, allowing the entire area of the depot to be queried. If the robot desires a specific component, it may only address its $Query$ messages to the desired component's ID number. However, if the robot seeks any part with suitable properties, such as a blue assembly strut, the robot may issue $Query$ messages using the $Broadcast\_ID$ number, and examine all responses for a match. When a match is found, the second phase of the algorithm begins. If the end of the depot is reached without finding a match, the algorithm terminates.

The second phase of the algorithm begins once communication has been established with a desired assembly component. During this phase, the FOV of the gripper's communication is exploited to accurately determine the position of the assembly material. The gripper is moved in one direction by small steps until the material leaves the gripper's FOV and communication is lost. At this time the gripper's position defines one end of the interval of successful communication. The robot now moves its gripper to the position at the end of phase one, reestablishing communication with the assembly material. The robot moves its gripper in the other direction until communication is again lost. The gripper's position now defines the other end of the interval of successful communication. Finally, the robot moves its gripper to the center of the interval of successful communication. In practice, the transmitting properties of the individual assembly components were found to be highly symmetric and repeatable, so moving to the center of the communication interval has proven a reliable means of centering the gripper over a component.

V. EXPERIMENTAL RESULTS

Experiments were performed with the assembly system to characterize the ability of the optical communication messaging infrastructure to identify assembly materials, and to characterize the reliability of using the gripper's FOV to perform the $Locate - and - Grasp$ algorithm. (Could also include some of the lower-level characterizations of the communication range, FOV, and character-transmission error rates)

To test the gripper's ability to identify materials, an assembly material was placed within the field of view of the gripper at a distance between 15 and 30cm. A single identification trial consists of the gripper issuing a $Query$ message to the component, and then listening for an ID message response. In the event that a message is received, but the message does not match its checksum, the gripper will

Algorithm 1 Localize-And-Grasp algorithm. $position\_tolerance$ and $depot\_length$ are supplied constants.

$stepSize \leftarrow \frac{FOV}{2}$
$fineStepSize \leftarrow position\_tolerance$
$armPosition \leftarrow 0$
while $armPosition \leq depot\_length$ **do**
  send $Query$
  if desired ID message received **then**
    while desired ID message received **do**
      send $Query$
      $armPosition \leftarrow armPosition - fineStepSize$
    end while
    $a \leftarrow armPosition$
    while desired component responds to query **do**
      send $Query$
      $armPosition \leftarrow armPosition - fineStepSize$
    end while
    $b \leftarrow armPosition$
    $armPosition \leftarrow \frac{a+b}{2}$
    lower gripper and grasp component
    return true
  else
    $armPosition \leftarrow armPosition + stepSize$
  end if
end while
return false

issue one additional $Query$ message. A success is recorded if an error-free ID message is received by the gripper after the first or second transmission.

The grasp testing evaluates the use of infrared communication to perform a line search for a desired component, align the gripper above the component, lower the manipulator and perform a successful grasp. A grasp is considered successful when the gripper closes completely around the assembly component.

For our experiments, it is assumed that the material's exact location is not known, but that it is required to be along an 4cm wide arc-shaped depot of fixed radius, rather than in a linear depot. This assumption was made due to the limited reach and accuracy of the robot's manipulator; sweeping the gripper in an arc by rotating the base of the manipulator was more practical for experiments than attempting to move the manipulator over a linear region. We assume that the assembly robot's knowledge of its position is sufficient for the robot to navigate to the parts depot. Within the parts depot, intelligent assembly struts and junctions may be placed. The components are not indexed into fixed positions, but their centerpoint must be within the depot.

Table I summarizes the results of these tests. In both sets of experiments, fewer than 1% of trials were failures. Failures result when communication is not established between the gripper and an assembly component within the gripper's field of view. Currently, the robot will make one attempt to resend a $Query$ message if a corrupted response is received; however, the assembly components will not acknowledge a corrupted request. The introduction of a Negative-Acknowledge (NACK) message or an error-correction scheme for these cases may further improve the reliability of establishing communication.

VI. Discussion

In this paper we describe the design of a robotic assembly system that uses line-of-sight optical communication between a robotic manipulator and assembly components to perform part identification and grasping. The design provides a computationally simple alternative to vision-based object detection and localization.

Optical communication, as a line-of-sight medium, implicitly conveys additional sensory information regarding proximity and unobstructed paths between the gripper and an assembly material. Our system utilizes the field of view of the optical components to determine the identity and relative position of nearby assembly materials.

Creating a sensory system from optical communication requires specification of the range and field of view of the optical transmitters and receivers. Short range and narrow fields of view provide valuable sensory information by heavily constraining the possible locations where a part within communication contact may be, but at the expense of making establishing communication difficult in the first place. In the context of robotic assembly, the tradeoff can be made by considering that certain interactions, such as manipulation, only take place between components within arm's reach of each other. This defines an upper limit on necessary range. Similarly, the needed field of view can be bounded by the degree of precision needed to align interacting components.

The hardware experiments using the assembly robot and construction materials showed that the communication infrastructure, localize-and-grasp algorithm, and compliant gripper design work successfully and with high reliability.

Our future goals for the assembly system include cooperative construction using multiple assembly robots to build 3D node-and-truss structures. Another goal is to expand the 1-D search algorithm to a 2-D raster seach.

VII. Acknowledgments

The authors would like to acknowledge the generous support of this project by the Boeing Corporation.

References

[1] a bibliography item

Type	Attemped	Successful	Success Rate	Failure Modality
Identify Component	1447	1446	99.9%	random bit error
Identify, Align, and Grasp	165	164	99.3	failed to identify part

TABLE I

SUMMARY OF EXPERIMENTAL RESULTS